Engineering for Earthquakes: Redefinition of the Original Roles

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Abstract

For most of this century, engineers have been aware of the effects of earthquakes on constructed facilities. The development of building codes has reflected the concern for the threat to public safety resulting from the severe damage or collapse of buildings and other structures. In the past several decades, great advances have been made in techniques for the analysis, design and construction of new buildings, resulting in a generally safer product. However, as recent earthquake events have shown, there is still the possibility, in the U.S. and elsewhere, for great loss of life and injury from inadequate structures. In response to this observation, it is suggested that the definition of earthquake engineering, or perhaps more appropriately "engineering for earthquakes," be redefined in a broader context which addresses more directly the public safety issue, and where necessary, the search and rescue problem. This paper summarizes the development of the current field of earthquake engineering, and outlines suggestions for a global framework into which earthquake engineering, architecture, medicine and epidemiology may fit to reduce the large potential losses in future earthquakes.

Introduction

Since ancient times, societies, however primitive, have been aware of the effects of earthquakes on their habitat, even though the source of the shaking and the mechanism of the destruction were often not understood. The Corinth, Greece earthquake of 856 AD is estimated to have killed 45,000; the Shensi, China event of 1556 about 830,000; the 1737 Calcutta, India earthquake: 300,000 (Bolt 1978). Most of these victims were killed by low-rise, poorly-constructed structures which had little or no lateral load resistance.

The effect of major earthquakes on large urban areas in the industrialized world was really first felt in the earthquake and subsequent fire in San Francisco in 1906. While

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the death toll of 700 was small in comparison to historical events, and actually many subsequent events in the 20th century, the potential for a larger disaster in terms of loss of life and economic consequences was evident. Contrasting the historical events, society questioned the adequacy of the structures in which it worked and lived, and engineers were called upon to produce structures which could resist earthquakes in a manner which reduced economic loss and improved life safety.

The development of building codes which reflected the lateral loads of wind and earthquake was started around that time as a result of the 1906 earthquake. San Francisco adopted a uniform 30 pound per square foot (psf) lateral design load which was to provide resistance to both wind- and earthquake-induced forces[2]. Throughout the subsequent decades, codes were introduced, modified, appended to, and corrected, in most cases in response to catastrophic events which caused significant damage, with or without loss of life. (Examples: The 1933 Long Beach earthquake, which caused significant damage to school buildings, but occurred at a time when school was not in session; as a result, the Field Act, which required school buildings be design for seismic loads, was introduced. The 1971 San Fernando earthquake (Jennings 1971) led to significant changes in design practice for highway bridges and, as a result of the collapse of the Veterans Administration hospital – which accounted for 49 of the 64 deaths attributed to the earthquake – and partial collapse of the then unoccupied Olive View Hospital, a heightened awareness of the performance

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[2] While consistent for wind loads, the "pressure" loading did not reflect the inertial load induced by earthquakes. Nonetheless, some lateral resistance was provided.

of critical facilities developed; the VA embarked on an extensive program to evaluate the adequacy of its facilities, which led to the extensive retrofit or demolition of many of its hospitals and the establishment of new design guidelines (VA 1973).)

A similar trend has occurred with what are commonly called secondary systems and nonstructural items. Secondary systems generally include large pieces of mechanical equipment which are attached to the building, or primary structure, in some way, but are not required for structural support. Dynamic interaction between these systems and the primary structure has often led to extensive damage, which often is, at least potentially, life threatening. The damage to the Sylmar electrical substation in the 1971 San Fernando earthquake (Jennings 1971) — many large transformers and other switchgear were destroyed — again led to the recognition of the importance of the performance of secondary systems. The effect of nonstructural walls and cladding on modifying the performance of the primary structure has long been a concern. More recently it has been recognized that building contents also pose a threat to life and limb and appropriate steps should be taken to secure them appropriately.

While current codes and suggested provisions (e.g., FEMA (1988), ICBO (1988)) estimate the seismic loads that new buildings are designed to withstand quite realistically (which includes allowances for building function, type of structural system, foundation effects, as well as the inherent dynamic properties of the structure and the location-specific seismic risk), there are still a number of unresolved areas which are of relevance here.

In this country and abroad, there are a large number of what may be termed "precode structures" which in some cities house a large proportion of the population. These buildings were constructed before the codes in effect at the time required consideration of seismic loads, and therefore offer little or no resistance to these lateral loads. The structural forms and the construction materials used are often highly unsuitable for seismic areas.

There are in some cases ambitious plans afoot to strengthen or remove these hazardous buildings (for example in California which has a "five-year plan.") However, there is often great economic, social and political pressure which hinders these actions. The result is that in this country, and throughout the world, there are thousands of buildings which are likely to collapse in moderate to major earthquakes. The recent examples in Mexico City, 1985 and Armenia, 1988 graphically demonstrate the hazard, and underscore the large human tragedy which results.

Also highlighted by the events mentioned above is the fact that when a building does collapse, for whatever reason, we are still not in a position to be able to effectively rescue trapped victims from the rubble. Systems for location of building inhabitants abound, but most are adaptations of technology developed for other applications, and virtually all are only marginally effective. Likewise, methods for the "delicate dismemberment" of a collapsed structure and the extrication of located victims are not well developed.

It is felt by the author that a major part of the problem is that there has not been a focussed research effort in this area. It is hoped that this workshop will be able to define some of the necessary research goals which may then be studied in the future. The purpose of this paper is to highlight the engineering aspects of the problem in a framework which addresses its interdisciplinary nature. Summarized are some suggestions for specific research thrusts which will improve our capability to locate and rescue trapped persons in future building collapses, and thereby reduce the high cost – in terms of human life and suffering – of future earthquake events.

Problem Definition

Figure 1 presents a flowchart which outlines the "earthquake process" globally, in an attempt to identify the critical issues and clarify the potential contribution of a redefined "engineering for earthquakes." Indicated in the diagram are the professions involved in the analysis or study of the various stages in the process, as well as the relevant inputs required.

The figure may be divided into three basic phases:

1. the earthquake and its consequences,
2. the response to the earthquake at a particular location, and
3. the recovery after the event.

The first phase, given by the top line, presents what has traditionally been the earthquake engineering process. Included are contributions from seismologists, geologists and geotechnical engineers who, working together, estimate a realistic level of expected ground acceleration at a site. The geotechnical and structural engineer then translates this information into a design load; analysis is performed and the structure designed accordingly. In many cases, these steps are handled in a simplified manner by the building codes and the services of a seismologist, geologist and sometimes even geotechnical engineer are not required.

Commonly, the job of the engineer is complete at this stage, save the supervision of the construction process. While due consideration has usually been given to the basic principles of seismic-resistant design[3], the engineer does not normally consider the possibility of collapse and the resulting consequences for occupants. For modern structures, this optimism may be justified but, as outlined earlier, collapse or severe damage of some older construction must be considered a certainty when a major earthquake affects an urban region.

Perhaps due to this "positive" attitude on the part of engineers with regard to their new construction (which is somewhat justified considering the performance of many newer buildings in both U.S. and worldwide earthquakes) that little study has been done which considers the actual collapse of structures. While the causes of earthquake-induced collapse have been identified in many structures over the years, and improvements in earthquake-resistant structural design resulted from their study, very little research has been directly

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[3] That is: (1) the structure should suffer no structural and only minor nonstructural damage in a "minor" earthquake; (2) the structure may suffer nonstructural damage and minor, repairable structural damage in a "moderate" earthquake; (3) the structure may suffer significant damage but should not collapse in a "major" earthquake. While the definitions of "minor," "moderate," and "major" are variable depending on location, type of structure, type of facility, etc., the basic "three-level" design principle is fairly well established.

aimed at investigating the ultimate failure modes of structures, and the resulting effects on inhabitants. The recent heightened awareness of the threat posed by older structures has led to a big push to implement evaluation and strengthening programs, but again little thought to how to deal with collapses should a major event occur *tomorrow*.

Referring back to Figure 1, this observation is represented as the split box for "effect on structure". While the basic response of a structure to earthquake loads is well understood, collapse – particularly of older structures – and collapse patterns have received little attention. It is, however, study of this type which is needed to begin to understand box 5: the effects of structural damage on occupants.

As indicated in the figure, this understanding of human effects cannot be accomplished by structural engineers alone. While the engineer can make contributions in analysis and prediction of collapse patterns, other factors, best understood by other professionals, are also important. While the details will be provided by my colleagues, it suffices to say that required are the services of

- architects, to study building layout, occupancy, egress patterns, population distributions, usage patterns, etc.,
- medical personnel, to identify and study where necessary the precise causes of death and injury of trapped victims, and
- epidemiologists, to relate the observations and factors obtained above in such a way as to enable substantive conclusions to be drawn and recommendations made for the

management of and response to future events.

The second phase indicated consists of the response phase, and is concerned with the delivery of relief, rescue and treatment activities after the event. Of prime concern is the location and extrication of trapped victims in the rubble of collapsed buildings. Paralleling and following this activity is the appropriate medical treatment, both on site and off site.

At this stage, the necessity for effective emergency management is apparent. In most significant events over the past decade, it has been clear that there was a lack of an organizational capability not only in the affected region, but also on site. The reasons for this are manyfold. The infrastructure is usually severely disrupted; local management capability is often minimal, and disorganized. International relief efforts are often not coordinated, and search and rescue activities often end up competitive, rather than cooperative. Even within a national team, an organizational structure is not apparent.

A major, and pertinent, reason for the management difficulties is, however, that there is really no disaster management role which is clearly defined and based on a solid body of research and past experience. Difficulties outlined above compound the problem. The results of studies in earthquake injury epidemiology can influence directly the management aspect. Training programs require establishment, ensuring adequately trained[4] personnel are available, at least at the national level, and perhaps ultimately at the international level also.

[4] Adequately trained implies trained in principles of engineering, architecture, emergency medicine and epidemiology, as well as management aspects.

Details of the medical and search and rescue aspects will be covered by my colleagues in their presentations.

The third and final phase is the recovery from the event. This refers in this context to the long-term medical, engineering, architectural and societal recovery. Again, it is envisioned that studies in earthquake injury epidemiology will impact directly on many of these aspects. In a basic way, this is evident in the reconstruction in Armenia: considerable effort has gone into making the new structures more earthquake resistant.

Recovery can also be linked to prevention. Recovery from one event can lead to preparedness for another, not necessarily in the same location. For example, there is a significant effort to improve earthquake preparedness in Southern California in anticipation of a large event. We do not have to wait for the event to strike to learn our lessons!

The New Role for Engineering:

Where does the "new" engineering for earthquakes fit into the above picture? It is clear from the discussion that the current scope of earthquake engineering is not comprehensive. Presented below, in summary form, is a series of areas into which engineers must delve to assist in the enhancement of life safety in future earthquake events.

- What is the ultimate performance of an engineered structure? Given that the three-level design approach has been used, the possibility of collapse is made as small as possible. Should a sufficiently large event occur, however, what will be the collapse scenario for the structure? Can this information be used in the design to enhance the possibility of survival even if a collapse should occur (e.g., safe corridors, etc.?)

- How should we characterize structural collapse from an epidemiological standpoint? Is a quantity such as volume fraction lost, etc., appropriate as an indicator of survivability potential?

- What are the most lethal building types from a structural engineering standpoint? Building on earthquake injury epidemiology studies, can we identify and those types of structure most likely to collapse in an "undesirable" manner and potentially killing or trapping large numbers of people? Information of this type can be used to assist in the prioritization of structures for retrofit procedures.

- What are the needs in search or location equipment? Can systems be developed which can penetrate the mixed environment of voids, concrete, masonry and steel to detect trapped victims. While some systems exist, none have been specifically designed for this environment, and as a result they are generally relatively ineffective.

- How should a collapsed structure be "dismantled" or penetrated in such a way as to rapidly reach trapped survivors, yet not risk the integrity of the remaining structure nor threaten the security of the victims? What are the stability characteristics of the collapsed structure?

The above list is not complete. There are sure to be other areas not specifically addressed which are of importance also. It is hoped that some of these will be identified in this workshop.

Conclusions

Presented above is an overview of the global earthquake problem, couched in a "human effects" context. A brief history of traditional earthquake engineering has been given, and its place in this context indicated.

It is clear from the discussion herein that the current role of engineering for earthquakes is not sufficiently broad to address the entire scope of the earthquake death and injury problem. The infant field of earthquake injury epidemiology needs contributions from many disciplines, especially engineering, to enable it to make an impact in reducing the toll in future events. Structural engineering is necessary to assist in the categorization of collapse and collapse patterns which may be used in the identification of potentially lethal structures; design changes and retrofit priorities and procedures can result. Other engineering disciplines may become involved in the development of location and extrication devices for the collapsed building environment.

The aim of this workshop is to identify the multidisciplinary field of earthquake injury epidemiology. Multidisciplinary implies both interdisciplinary and intradisciplinary. New considerations for engineers fall in to both categories. The preceding paper outlines the author's view of some of the important engineering contributions required. Coupled with those of my colleagues, and the outcome of the discussions of the workshop, we hope we will be able to enhance significantly the development of a field which will reduce significantly the loss of life and hardship produced in future earthquakes.

Appendix I – References

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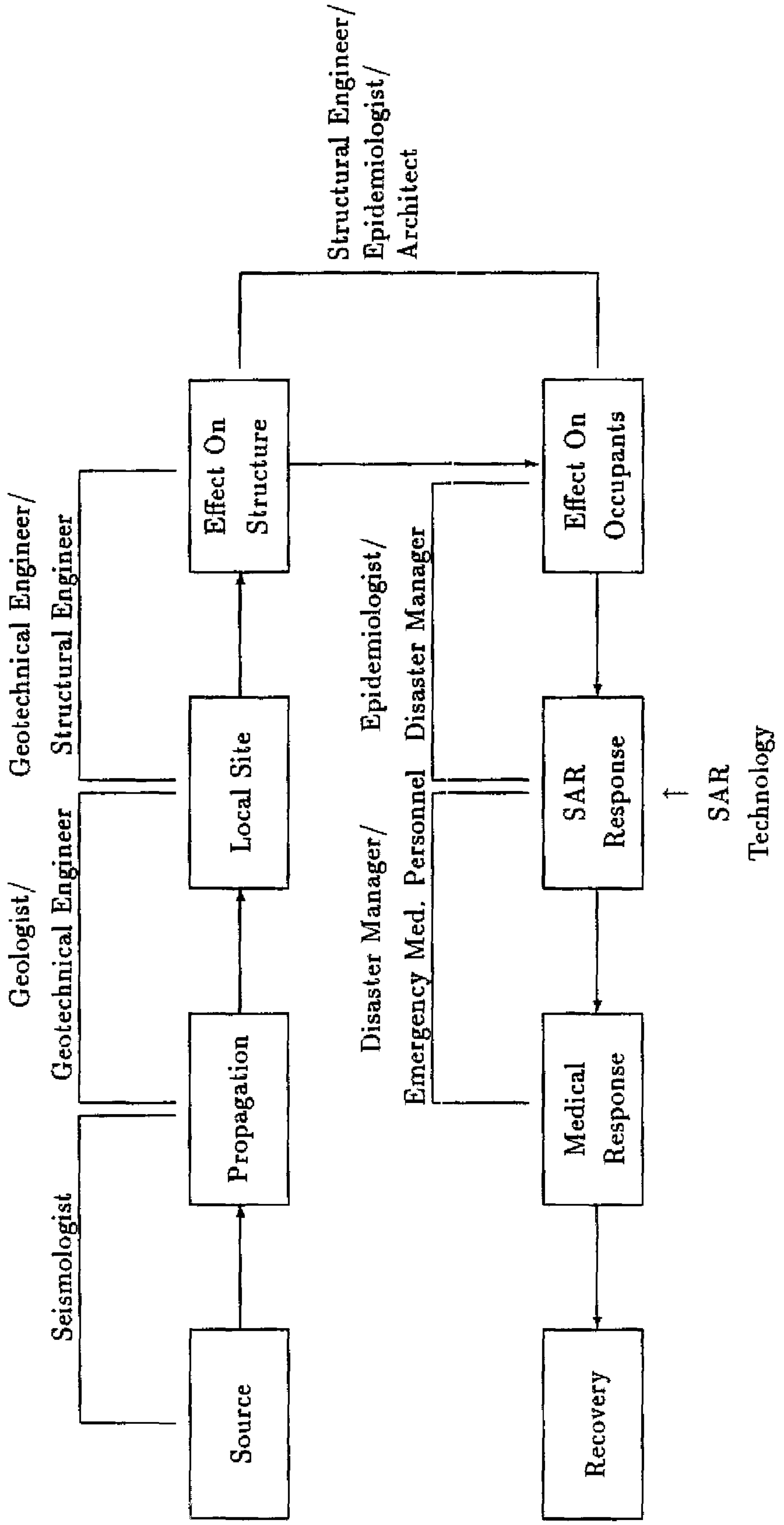

Figure 1: Flowchart of the "Earthquake Process."